



ARNOLD LIGHTWEIGHT MIRROR MODELER

VERSION 2.0

**WILLIAM R. ARNOLD, SR
DEFENSE ACQUISITION, INC
(SUBCONTRACT WITH JACOBS ESTS)
HUNTSVILLE, ALABAMA**

**H. PHILIP STAHL
NASA MSFC, HUNTSVILLE, AL.**



HERITAGE



- **SECOND GENERATION OF EGGCRATE MODELER DEVELOPED AT L3-COMM BRASHEAR, PITTSBURGH, PA. USED TO DESIGN PRIMARY MIRROR, SUPPORT SYSTEM AND MIRROR HANDLING EQUIPMENT FOR THE KEPLER PLANET FINDER.**
- **COMPLETE REWRITE FOR USE ON WINDOWS 7 AND ABOVE OPERATING SYSTEMS.**
- **EXPANDED TO MULTI-SEGMENT MIRROR AS WELL AS SINGLE MIRROR SYSTEMS.**

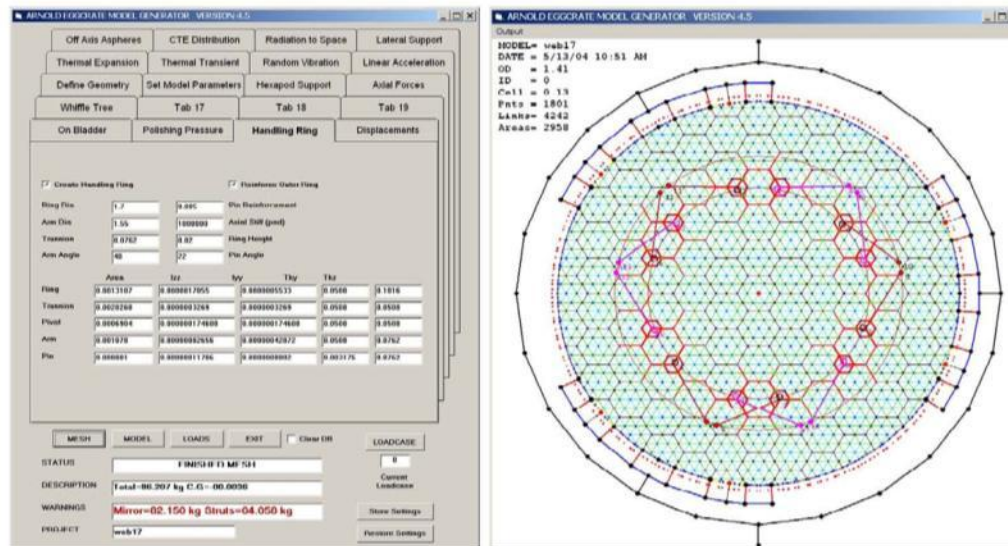


INTEGRATED PRODUCT DESIGN



Ball Aerospace
& Technologies Corp.

Integrated Design of Handling Equipment



Design tool allows evaluation and design of handling fixtures during the preliminary design of the mirror blank. As mirrors become lighter, the difficulties of handling the glass during manufacturing requires careful attention to these operations. Special reinforced features were added to the blank specifically to aid the manufacturing process and reduce risk.





CONVERT ANALYSIS TO DESIGN

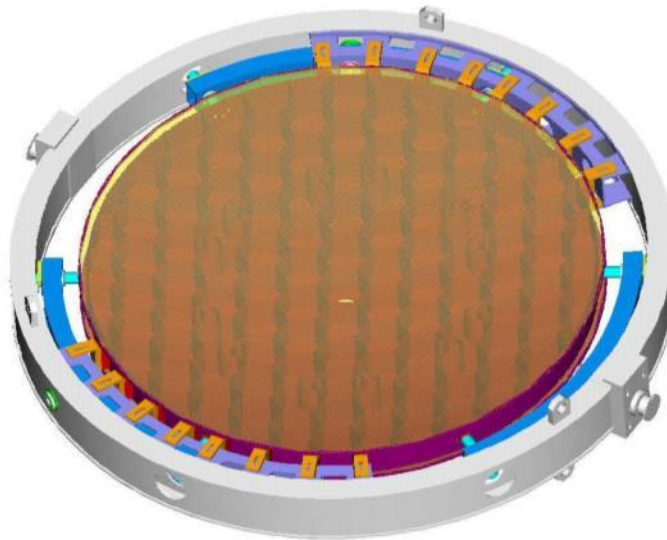


CORNING



Ball Aerospace
& Technologies Corp.

Primary Mirror in Flipping Ring



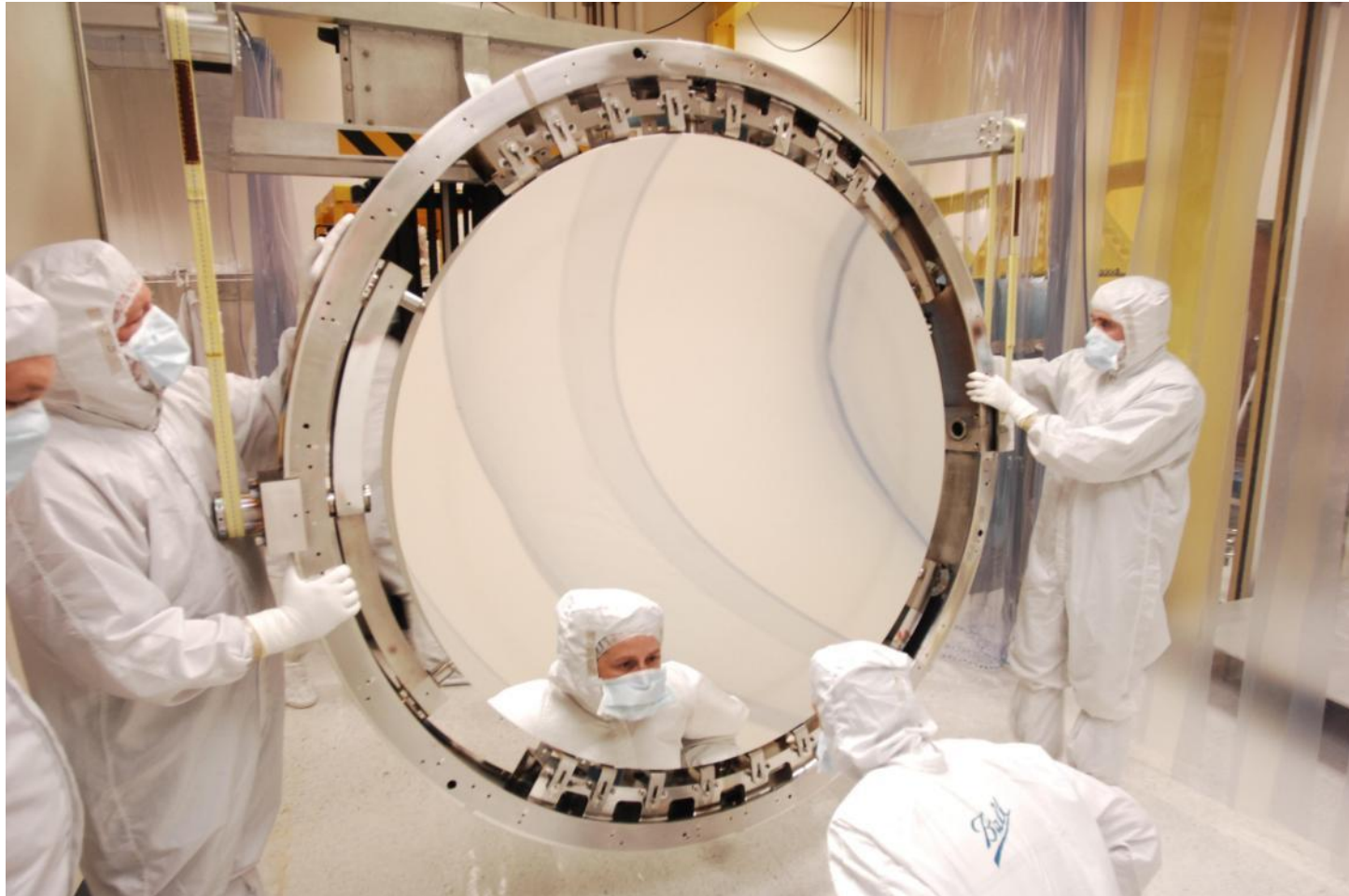
The handling ring interfaces with special reinforced slots in the mirror core. With the addition of storage shields, the unit can act as a temporary container. Does not touch optical surfaces or fragile edges.



NASA Tech Days 2004



THE FINAL PRODUCT





PROGRAM CONTROL WINDOW



Arnold Lightweight Mirror Modeler (Ver 2.0) [X]

Outer Dia	2
Inner Dia	0.25
Cell Width	0.3
Lip Inner	0.05
Segment Lip	0.05
Mirror Lip	0.1
Num Rings	0
Sgmt Span	1
Sgmt Gap	0.15
Merge Tol	0.025
Grid Zoom	1
Segment Shown	1
Srink Factor	0.05

Supports

☐ Each Segment

☒ Whole Mirror

☒ Show Whole Grid

☐ Show Supports

☐ Show Fillets

DISPLAY GRID

DISPLAY MODEL

WRITE MODEL

SAVE **RESTORE**

MERGE NODES

Modal (PSD) **Boule Mapping**

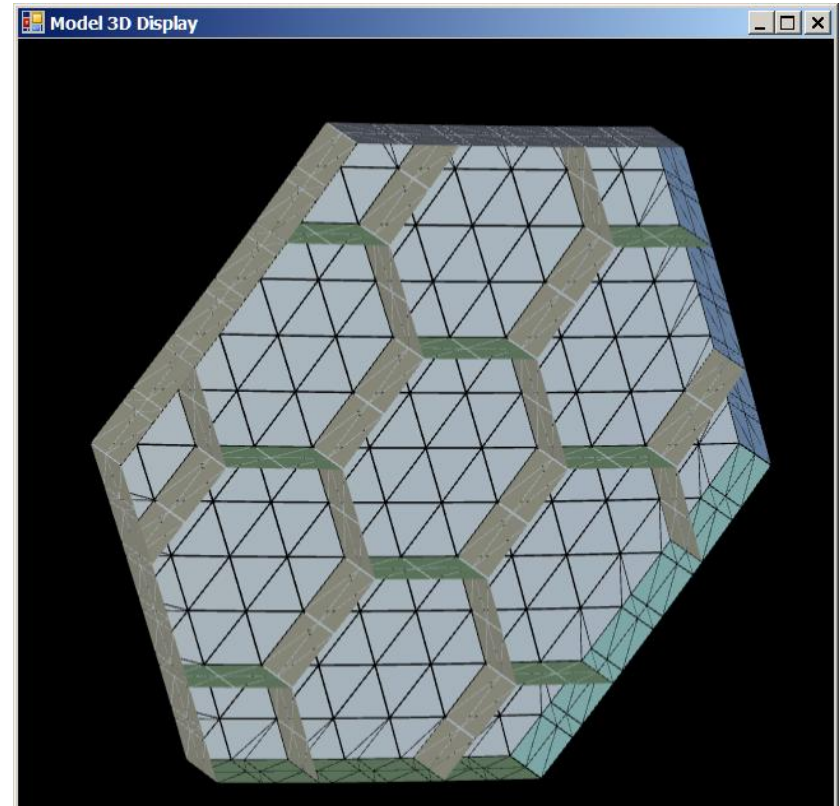
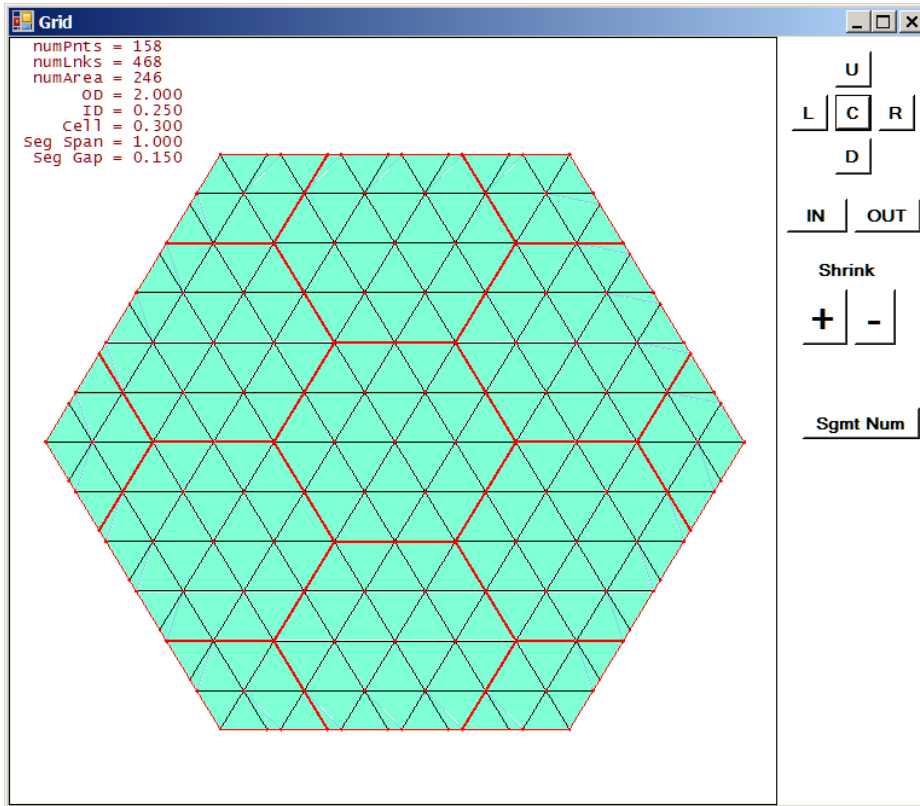
Grid Options **Optical** **Reals** **Core** **Hexapod** **Axial** **Radial** **Inertial Loads**

<input type="checkbox"/> Outer Sgmt Lip	<input type="checkbox"/> Isogrid Front	<input type="radio"/> Cell Level 0
<input type="checkbox"/> Outer Mirror Lip	<input type="checkbox"/> Isogrid Back	<input type="radio"/> Cell Level 1
<input type="checkbox"/> Inner Mirror Lip	<input type="checkbox"/> Backface Holes	<input checked="" type="radio"/> Cell Level 2
<input type="checkbox"/> Circular Segment	<input type="checkbox"/> Core Projection	
<input type="checkbox"/> Circular Mirror	<input type="checkbox"/> Include Fillets	
<input checked="" type="checkbox"/> Seal Ring Outer	<input type="checkbox"/> Off Center Pattern	
<input checked="" type="checkbox"/> Seal Ring Inner	<input type="checkbox"/> No Backsheet	
<input checked="" type="checkbox"/> Seal Ring Mirror	<input type="checkbox"/> Central Hole	
<input type="checkbox"/> Segment Lip Ribs		

Status []

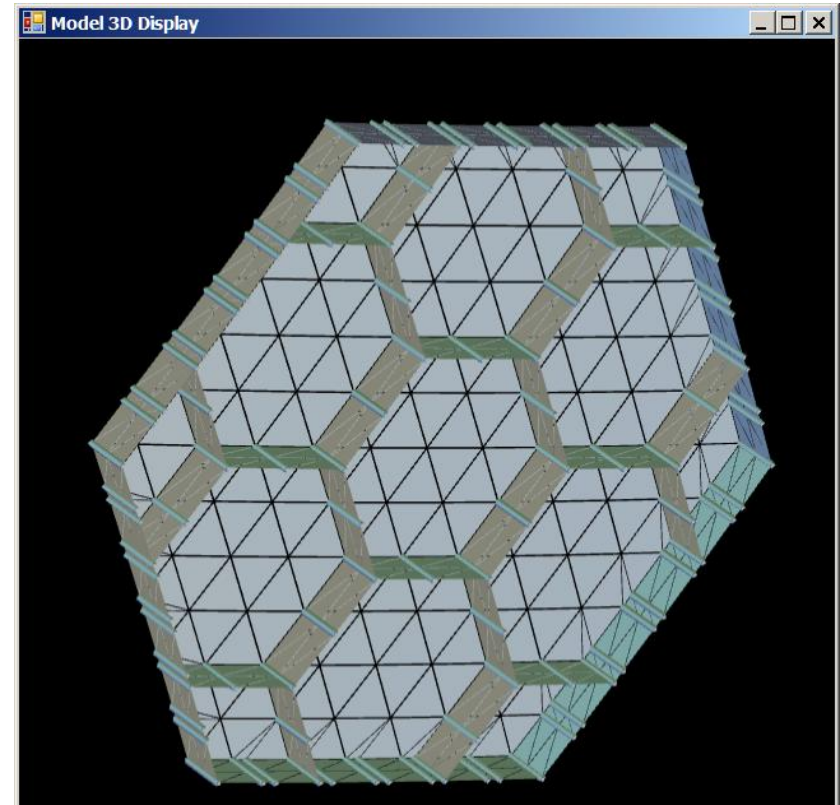
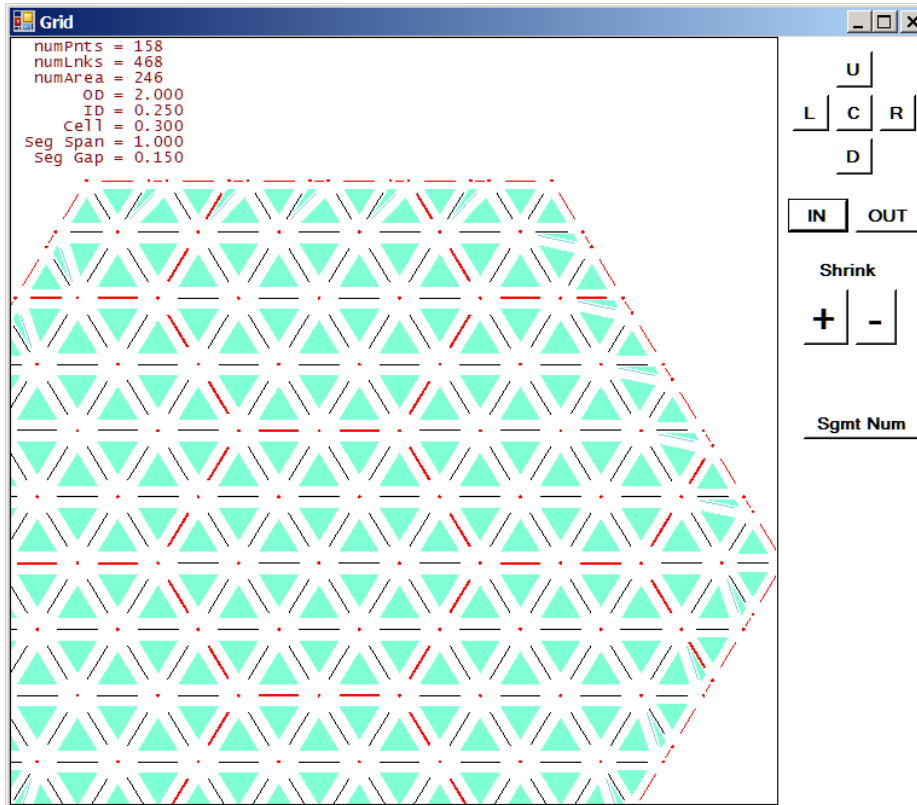


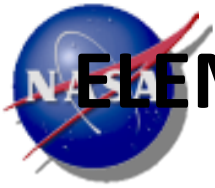
BOTH 2D AND 3D DISPLAYS





GUI ALLOWS PAN AND ZOOM





ELEMENT SHRINK HELPS UNDERSTAND MESH



Arnold Lightweight Mirror Modeler (Ver 2.0)

Outer Dia	2
Inner Dia	0.25
Cell Width	0.3
Lip Inner	0.05
Segment Lip	0.05
Mirror Lip	0.1
Num Rings	0
Sgmt Span	1
Sgmt Gap	0.15
Merge Tol	0.025
Grid Zoom	1
Segment Shown	1
Srink Factor	0.3

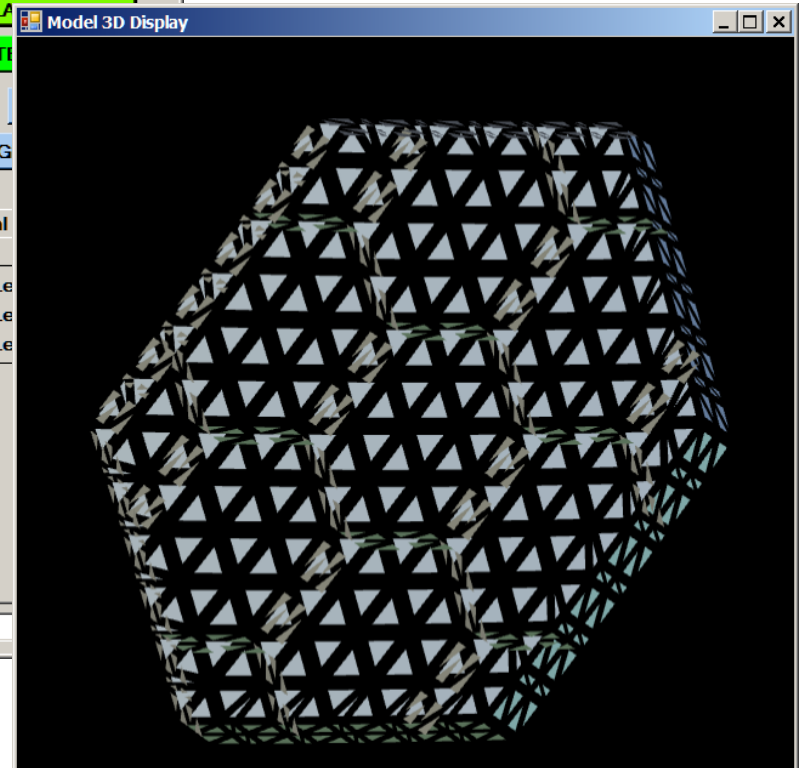
Model Statistics	
474	num Nodes
1153	num Elems
20.52155	Weight (kg)
1.827647	Area (m ²)
11.2284	W/A (kg/m ²)

Supports	
<input type="radio"/> Each Segment	
<input checked="" type="radio"/> Whole Mirror	
<input checked="" type="checkbox"/> Show Whole Grid	
<input type="checkbox"/> Show Supports	
<input type="checkbox"/> Show Fillets	

Modal (PSD)	Boule Mapping
Grid Options	Optical Reals Core Hexapod Axial Radial Inertial
<input type="checkbox"/> Outer Sgmt Lip	<input type="checkbox"/> Isogrid Front
<input type="checkbox"/> Outer Mirror Lip	<input type="checkbox"/> Isogrid Back
<input type="checkbox"/> Inner Mirror Lip	<input type="checkbox"/> Backface Holes
<input type="checkbox"/> Circular Segment	<input type="checkbox"/> Core Projection
<input type="checkbox"/> Circular Mirror	<input checked="" type="checkbox"/> Include Fillets
<input checked="" type="checkbox"/> Seal Ring Outer	<input type="checkbox"/> Off Center Pattern
<input checked="" type="checkbox"/> Seal Ring Inner	<input type="checkbox"/> No Backsheet
<input checked="" type="checkbox"/> Seal Ring Mirror	<input type="checkbox"/> Central Hole
<input type="checkbox"/> Segment Lip Ribs	

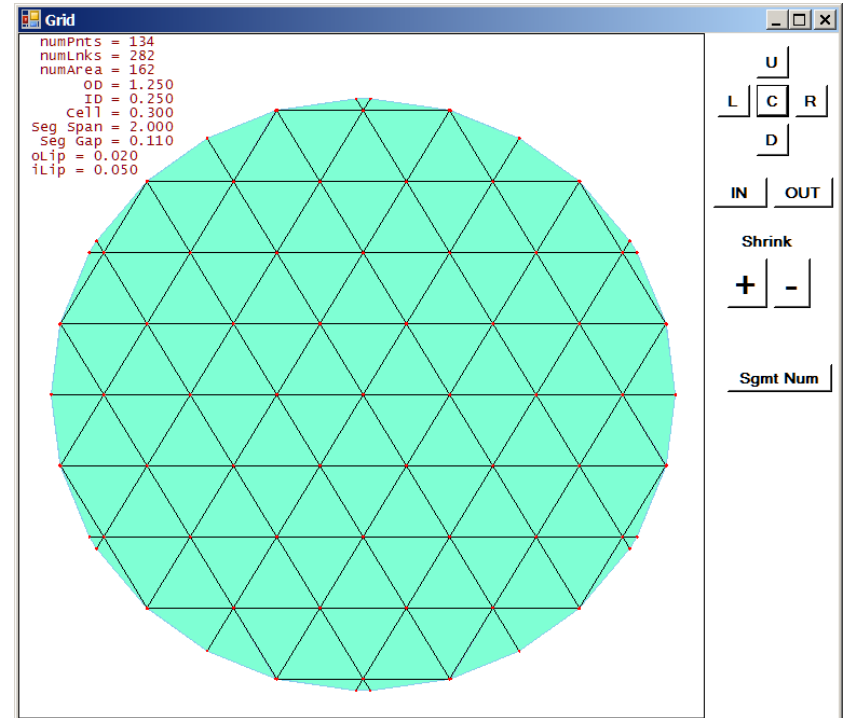
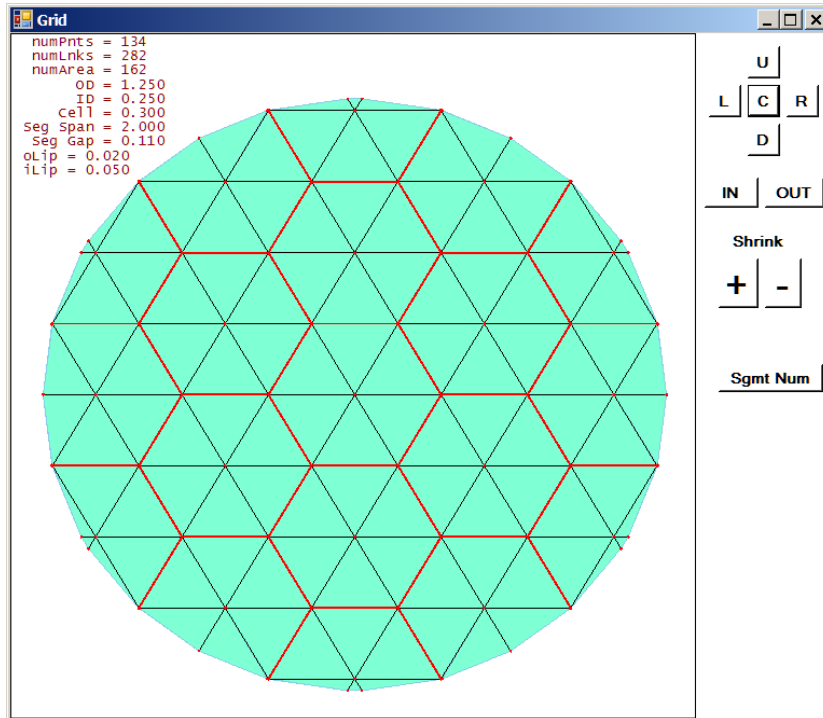
Buttons: DISPLAY GRID, DISPLAY, WRITE, SAVE, MERGE

Status: Finished Making Model



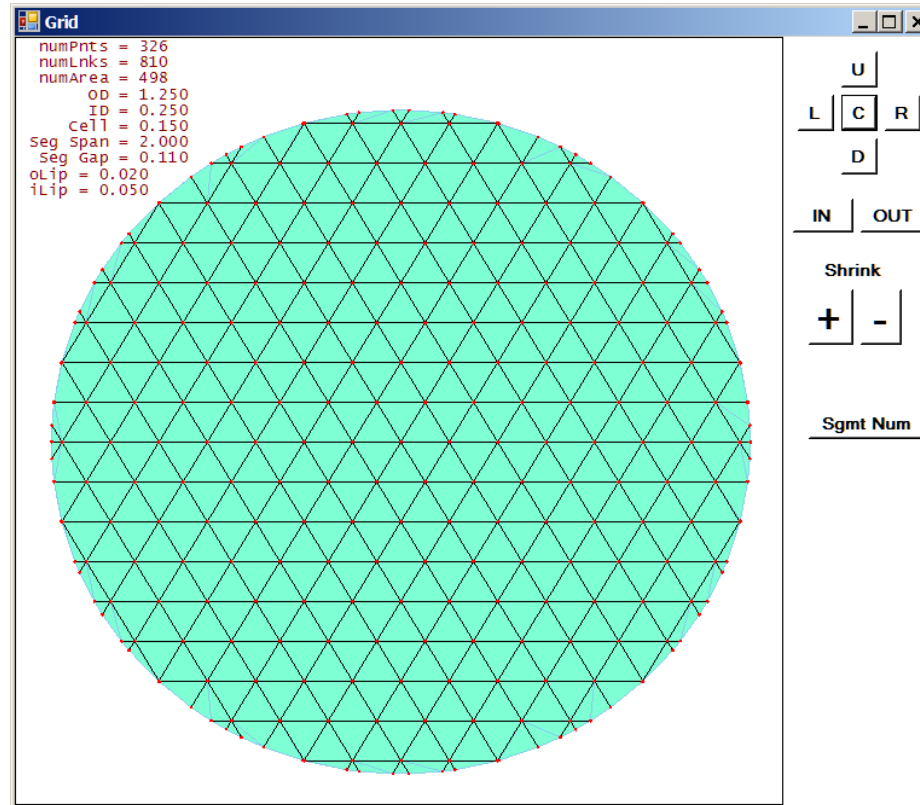


ALSO ISOGRID AND SIMPLIFIED MESHES



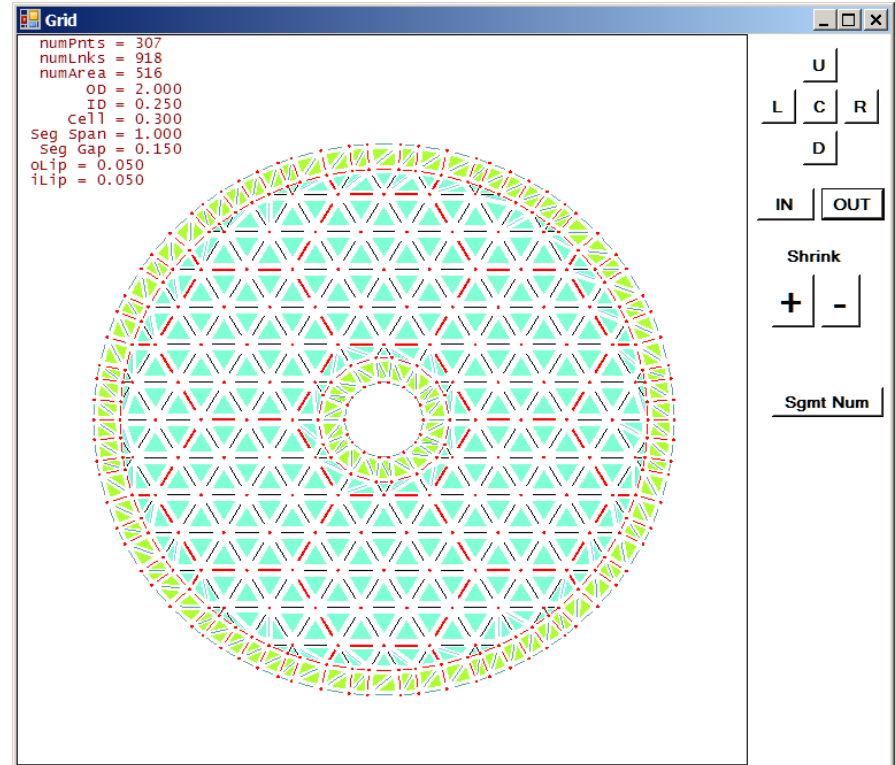
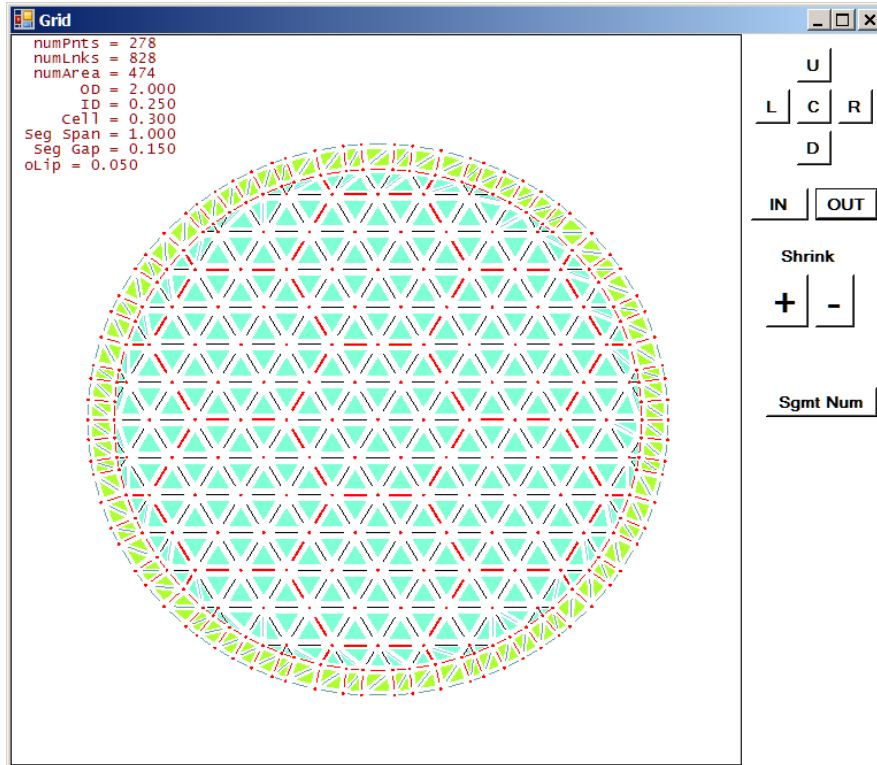


QUICKLY REMESH



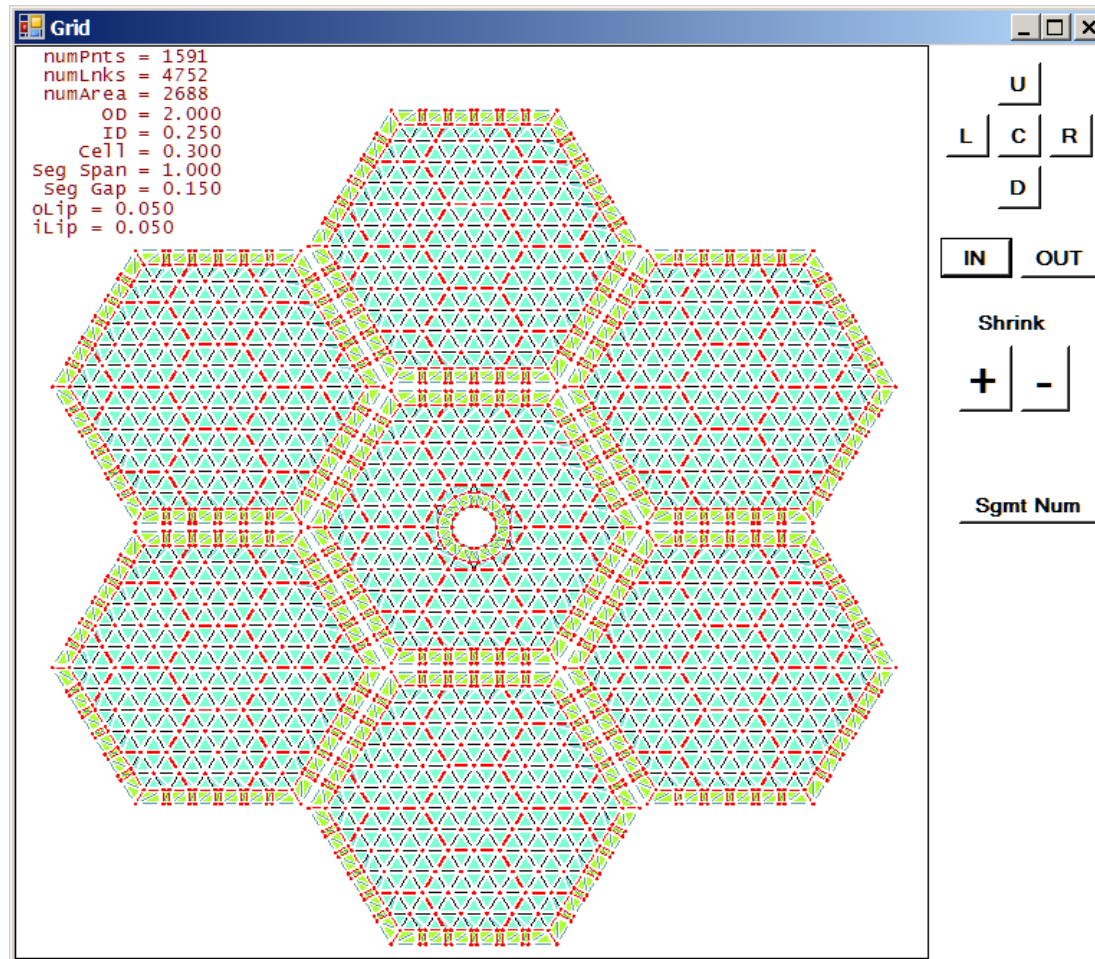


ADD CENTRAL HOLE EASILY



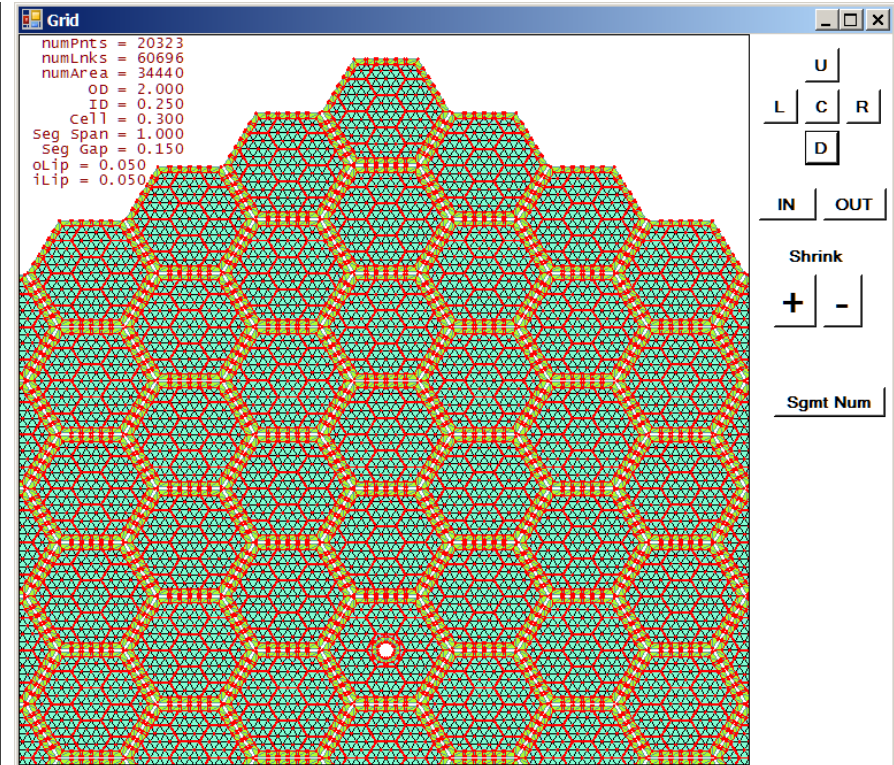
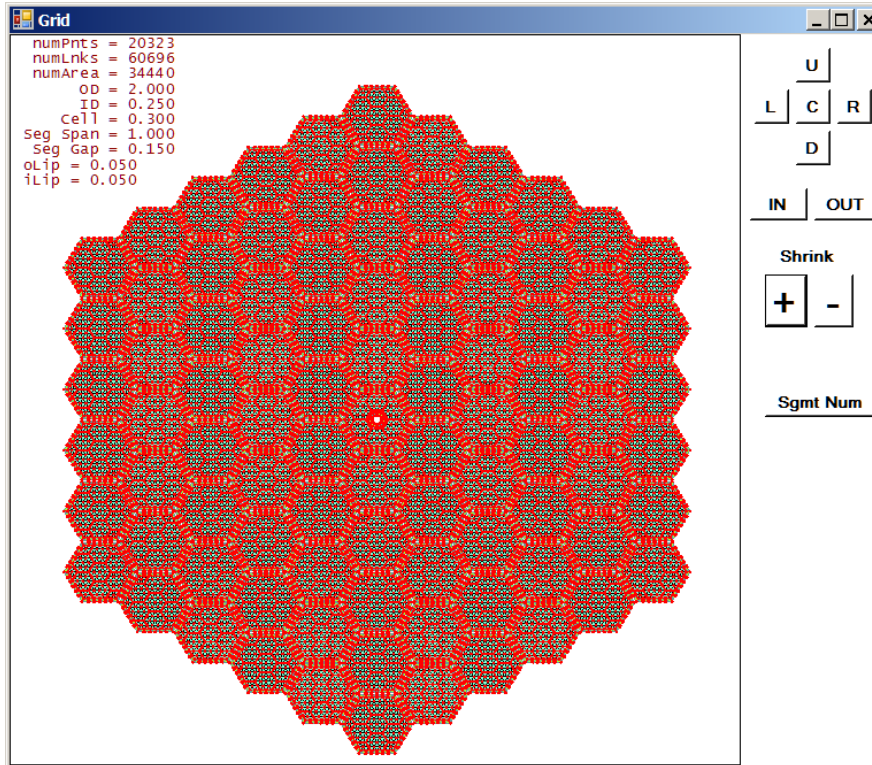


MODEL SEGMENTED MIRRORS



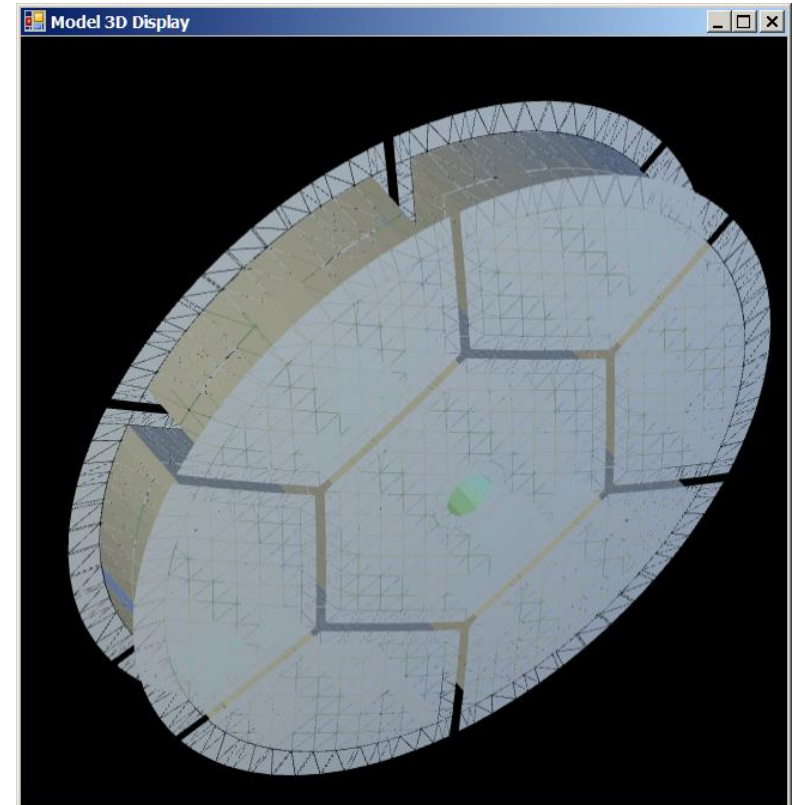
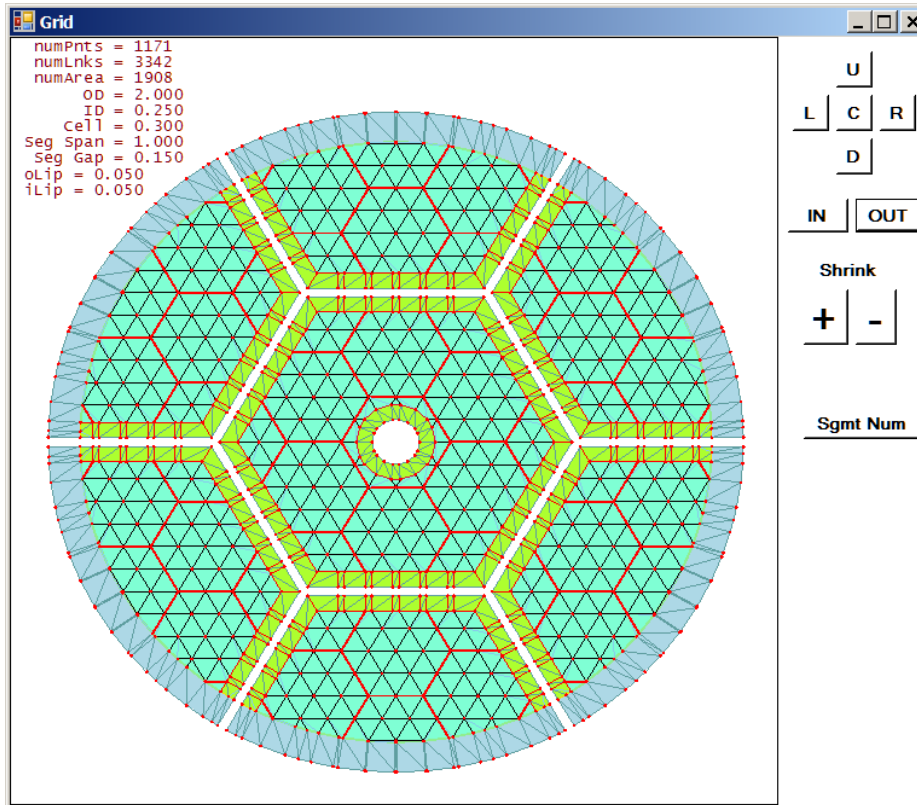


ALMOST UNLIMITED SIZE



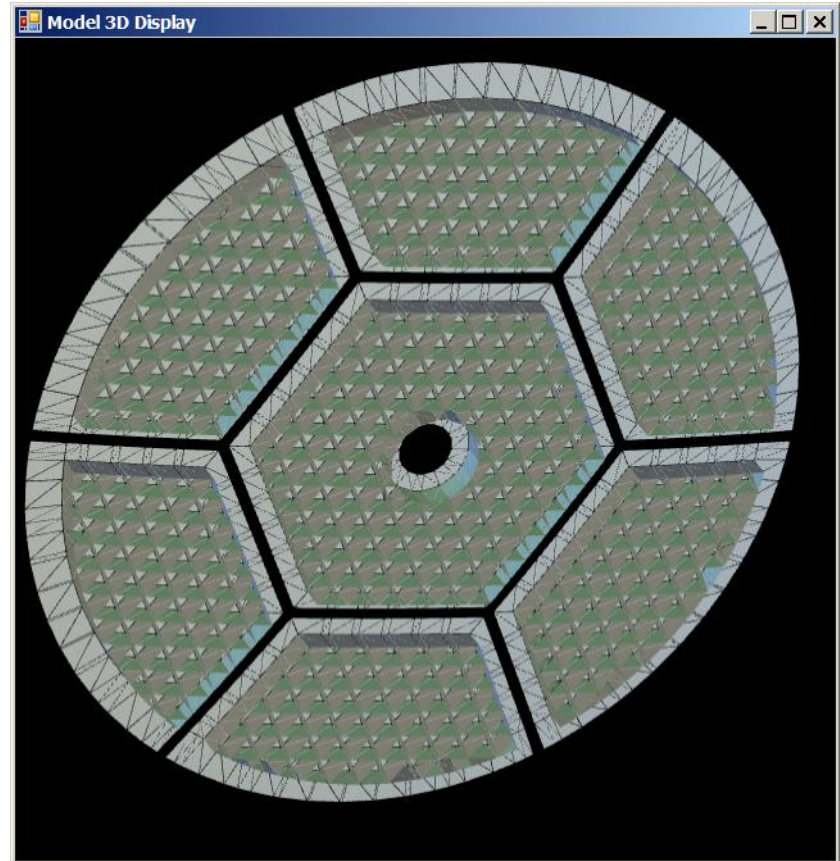
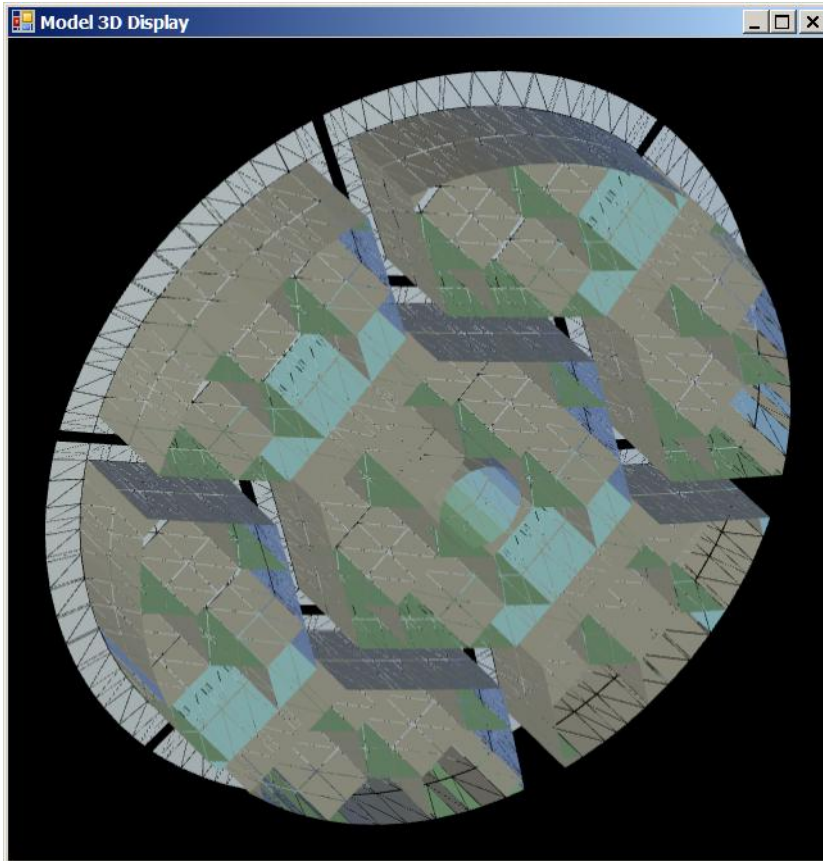


MODEL CIRCULAR SEGMENTED MIRRORS



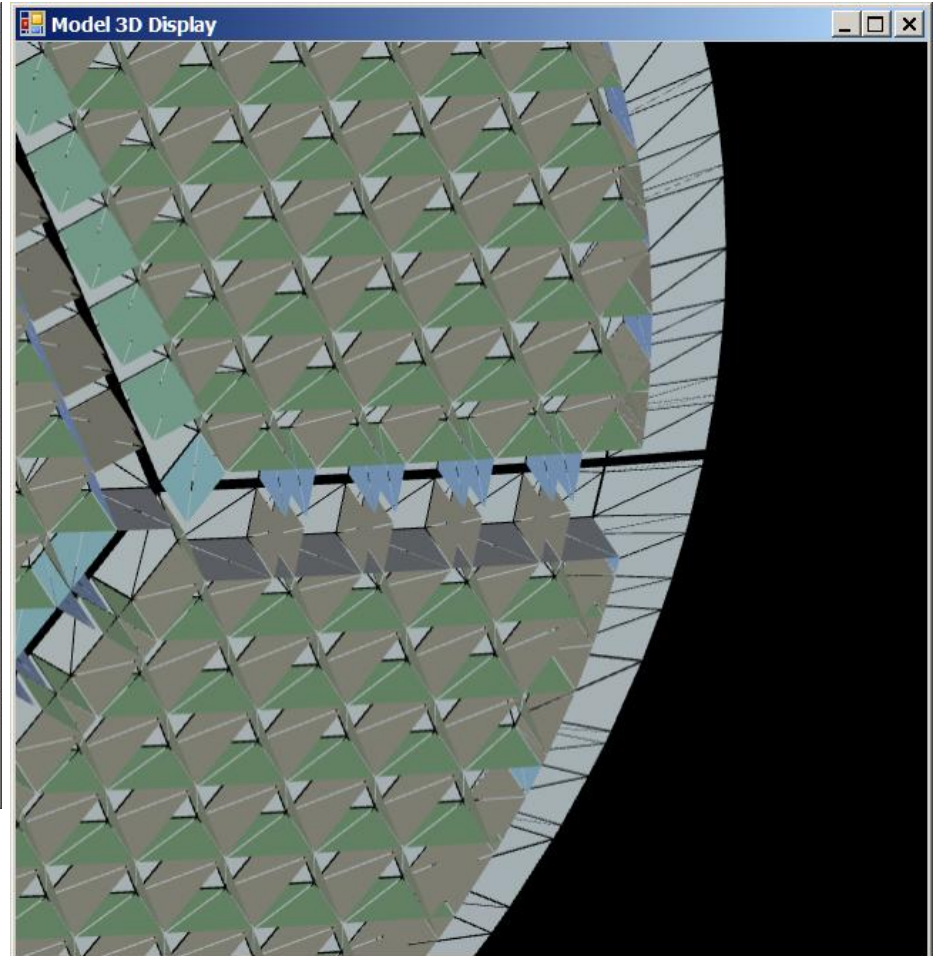
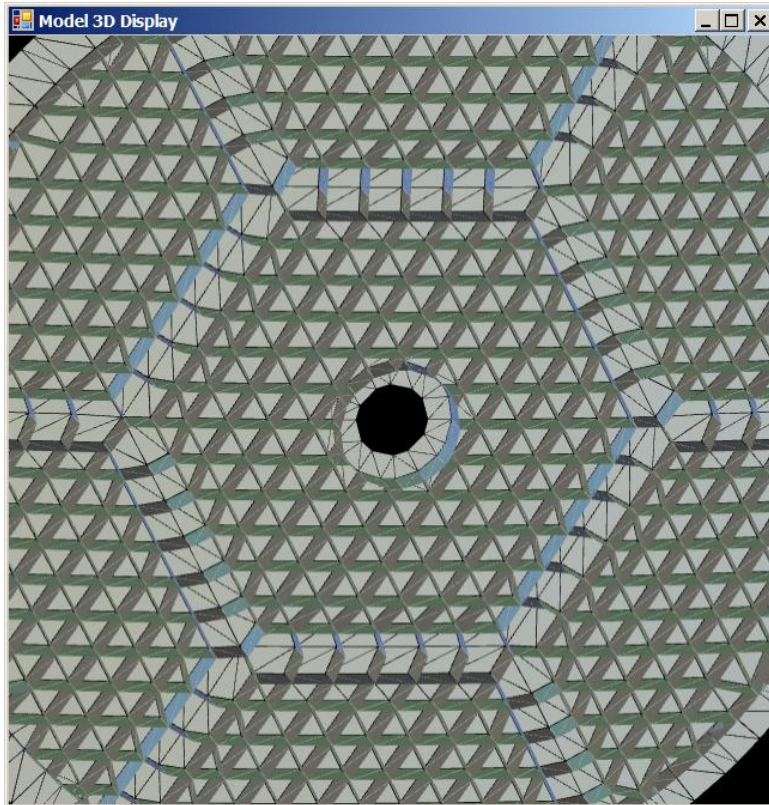


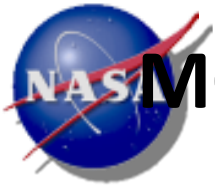
SUPPORTS ISOGRID FACESHEETS



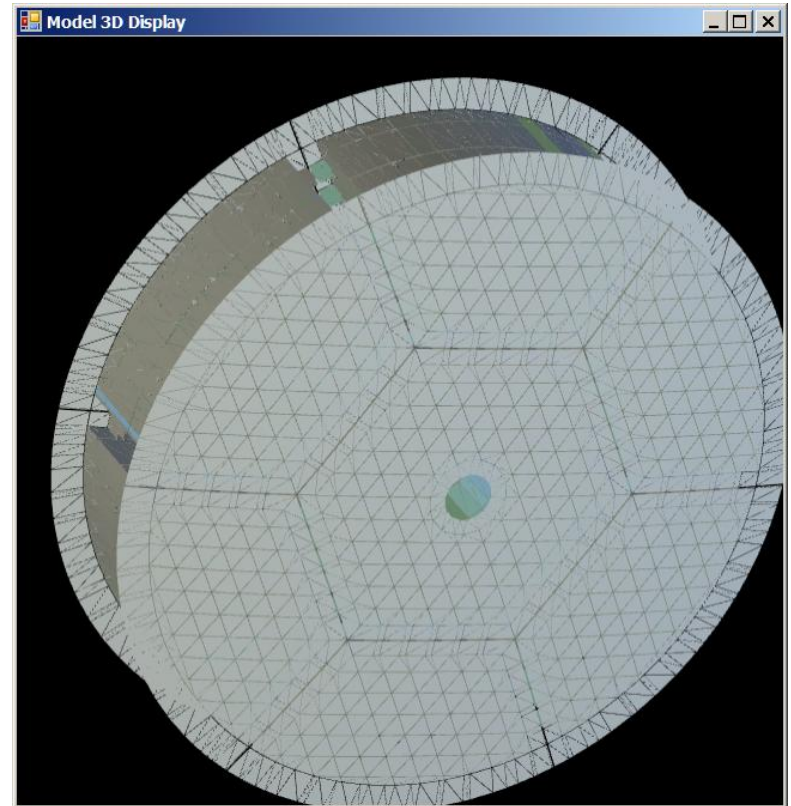
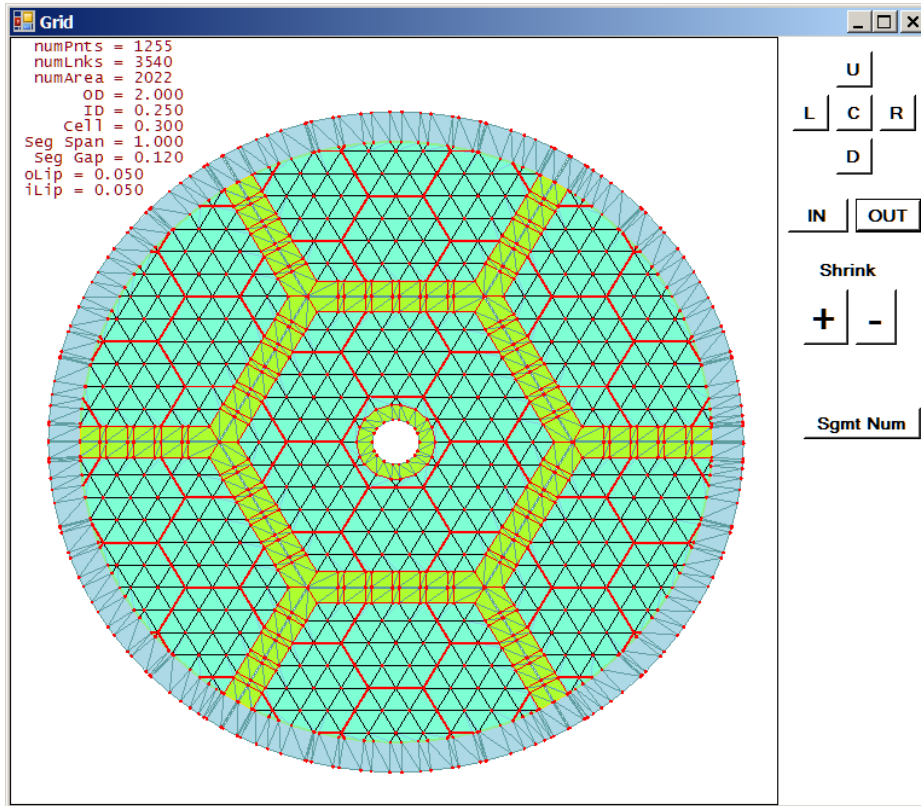


EDGES CAN HAVE RIBS



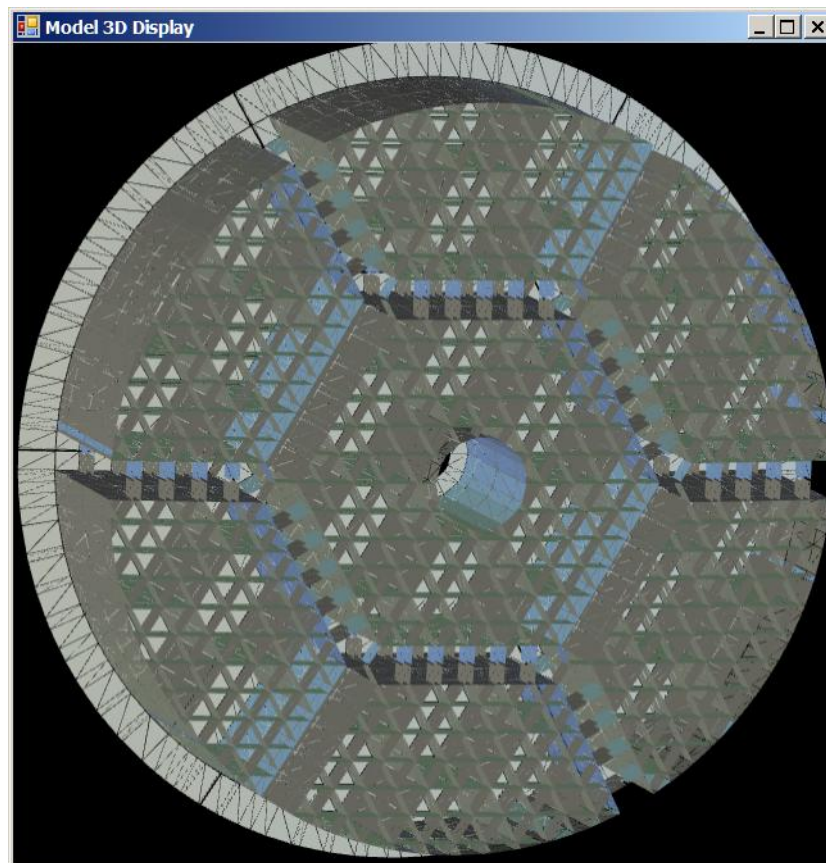
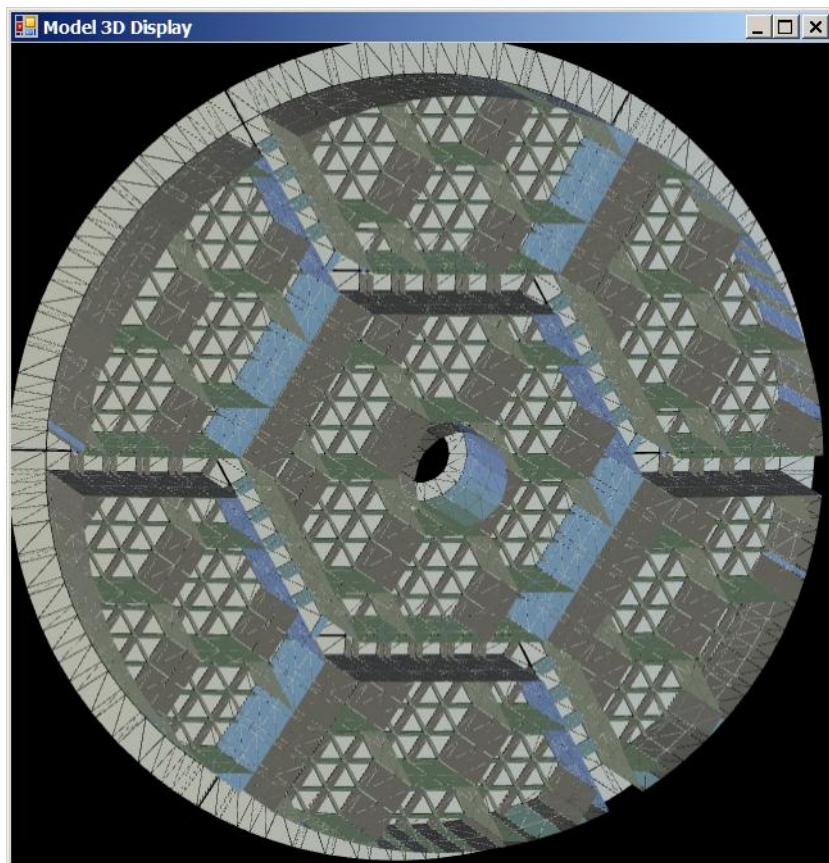


MODEL CAN BE MERGED IN ONE MIRROR



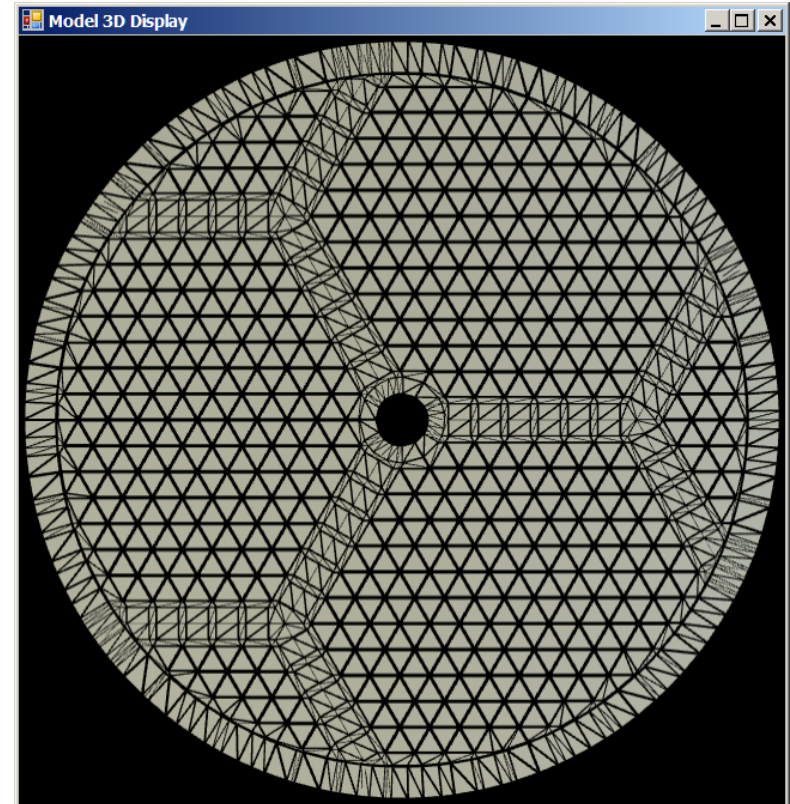
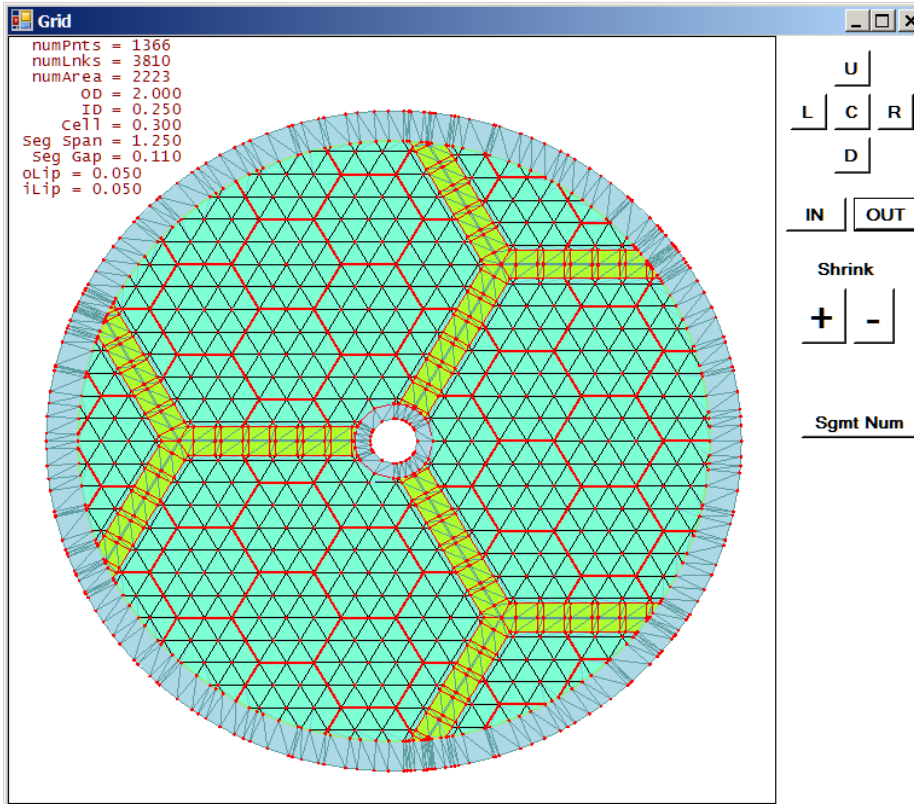


FRONT AND BACK ISOGRIDS SUPPORTED





OFFSET SUPER-CELLS SUPPORTED





WITH OR WITHOUT SEAL RINGS





MODEL STATISTICS ON THE FLY



Arnold Lightweight Mirror Modeler (Ver 2.0)

Outer Dia	2	Model Statistics		Supports		DISPLAY GRID	
Inner Dia	0.25	6830	num Nodes	<input type="radio"/> Each Segment	DISPLAY MODEL		
Cell Width	0.3	15751	num Elems	<input checked="" type="radio"/> Whole Mirror	WRITE MODEL		
Lip Inner	0.05	206.4664	Weight (kg)	<input checked="" type="checkbox"/> Show Whole Grid	SAVE RESTORE		
Segment Lip	0.05	17.01546	Area (m ²)	<input type="checkbox"/> Show Supports	MERGE NODES		
Mirror Lip	0.1	12.13405	W/A (kg/m ²)	<input type="checkbox"/> Show Fillets			

Num Rings: 2
Sgmt Span: 1.25
Sgmt Gap: 0.11
Merge Tol: 0.025
Grid Zoom: 0.99
Segment Shown: 1
Sink Factor: 0.12

Modal (PSD) | Boule Mapping

Grid Options | Optical | Reals | Core | Hexapod | Axial | Radial | Inertial Loads

<input checked="" type="checkbox"/> Outer Sgmt Lip	<input checked="" type="checkbox"/> Isogrid Front	<input type="radio"/> Cell Level 0 <input type="radio"/> Cell Level 1 <input checked="" type="radio"/> Cell Level 2
<input checked="" type="checkbox"/> Outer Mirror Lip	<input checked="" type="checkbox"/> Isogrid Back	
<input checked="" type="checkbox"/> Inner Mirror Lip	<input type="checkbox"/> Backface Holes	
<input type="checkbox"/> Circular Segment	<input type="checkbox"/> Core Projection	
<input checked="" type="checkbox"/> Circular Mirror	<input type="checkbox"/> Include Fillets	
<input checked="" type="checkbox"/> Seal Ring Outer	<input checked="" type="checkbox"/> Off Center Pattern	
<input checked="" type="checkbox"/> Seal Ring Inner	<input type="checkbox"/> No Backsheet	
<input checked="" type="checkbox"/> Seal Ring Mirror	<input checked="" type="checkbox"/> Central Hole	
<input checked="" type="checkbox"/> Segment Lip Ribs		

Status: 21 elems with bad aspect ratios



ANY OPTIC SUBSCRIPTION SUPPORTED



Arnold Lightweight Mirror Modeler (Ver 2.0)

Outer Dia	2	Model Statistics		Supports		DISPLAY GRID	
Inner Dia	0.25	6830	num Nodes	<input type="radio"/> Each Segment	DISPLAY MODEL		
Cell Width	0.3	15751	num Elems	<input checked="" type="radio"/> Whole Mirror	WRITE MODEL		
Lip Inner	0.05	206.4664	Weight (kg)	<input checked="" type="checkbox"/> Show Whole Grid	SAVE RESTORE		
Segment Lip	0.05	17.01546	Area (m ²)	<input type="checkbox"/> Show Supports	MERGE NODES		
Mirror Lip	0.1	12.13405	W/A (kg/m ²)	<input type="checkbox"/> Show Fillets			

Num Rings	2	Modal (PSD)		Boule Mapping						
Sgmt Span	1.25	Grid Options		Optical	Reals	Core	Hexapod	Axial	Radial	Inertial Loads
Sgmt Gap	0.11	Radius		7.5	Coefficient(1)		0			
Merge Tol	0.025	Conic		-1	Coefficient(2)		0			
Grid Zoom	0.99	Aspheric Order		0	Coefficient(3)		0			
Segment Shown	1				Coefficient(4)		0			
Srink Factor	0.12				Coefficient(5)		0			

Status 21 elems with bad aspect ratios



CONTROL OVER MOST VARIABLES



Arnold Lightweight Mirror Modeler (Ver 2.0)

Outer Dia	2
Inner Dia	0.25
Cell Width	0.3
Lip Inner	0.05
Segment Lip	0.05
Mirror Lip	0.1
Num Rings	2
Sgmt Span	1.25
Sgmt Gap	0.11
Merge Tol	0.025
Grid Zoom	0.99
Segment Shown	1
Srink Factor	0.12

Model Statistics		
6830	num Nodes	
15751	num Elms	
206.4664	Weight (kg)	
17.01546	Area (m^2)	
12.13405	W/A (kg/m^2)	

Supports

☐ Each Segment

☒ Whole Mirror

☒ Show Whole Grid

☐ Show Supports

☐ Show Fillets

DISPLAY GRID

DISPLAY MODEL

WRITE MODEL

SAVE **RESTORE**

MERGE NODES

Modal (PSD)		Boule Mapping					
Grid Options	Optical	Reals	Core	Hexapod	Axial	Radial	Inertial Loads
r, 1	0.005	Front Facesheet	<input checked="" type="checkbox"/> Show				
r, 2	0.005	Back Facesheet	<input type="checkbox"/> Show				
r, 3	0.005	Front IsoGrid Web	<input checked="" type="checkbox"/> Show				
r, 4	0.005	Outer Seal Ring	<input checked="" type="checkbox"/> Show				
r, 5	0.005	Inner Seal Ring	<input checked="" type="checkbox"/> Show				
r, 6	0.005	Core Web	<input checked="" type="checkbox"/> Show				
r, 7	0.005	Back IsoGrid Web	<input type="checkbox"/> Show				
r, 8	0.015	Front Outer Seg Lip	<input checked="" type="checkbox"/> Show				
r, 9	0.015	Back Outer Seg Lip	<input type="checkbox"/> Show				

Mirror Material

☒ ULE

☐ Zerodur

☐ E6

☐ Fused Silica

☐ BK7

☐ Silicon Carbide

Status 21 elems with bad aspect ratios



CONTROL OVER CORE DESIGN



Arnold Lightweight Mirror Modeler (Ver 2.0)

Outer Dia	2	Model Statistics		Supports		DISPLAY GRID	
Inner Dia	0.25	6830	num Nodes	<input type="radio"/> Each Segment	DISPLAY MODEL		
Cell Width	0.3	15751	num Elems	<input checked="" type="radio"/> Whole Mirror	WRITE MODEL		
Lip Inner	0.05	206.4664	Weight (kg)	<input checked="" type="checkbox"/> Show Whole Grid	<input type="checkbox"/> Show Supports	<input type="checkbox"/> Show Fillets	SAVE RESTORE
Segment Lip	0.05	17.01546	Area (m ²)	MERGE NODES			
Mirror Lip	0.1	12.13405	W/A (kg/m ²)				

Num Rings	2	Modal (PSD)		Boule Mapping																					
Sgmt Span	1.25	Grid Options	Optical	Reals	Core	Hexapod	Axial	Radial	Inertial Loads																
Sgmt Gap	0.11	<table border="1"><tr><td>Front Depth</td><td>0.0254</td></tr><tr><td>Core Depth</td><td>0.0762</td></tr><tr><td>Back Depth</td><td>0.0254</td></tr><tr><td>Total Depth</td><td>0.127</td></tr><tr><td>Core Layers</td><td>2</td></tr><tr><td colspan="2">CoreWeb Fillet Radius</td><td>0.005</td></tr><tr><td colspan="2">IsoGrid Fillet Radius</td><td>0.005</td></tr></table>								Front Depth	0.0254	Core Depth	0.0762	Back Depth	0.0254	Total Depth	0.127	Core Layers	2	CoreWeb Fillet Radius		0.005	IsoGrid Fillet Radius		0.005
Front Depth	0.0254																								
Core Depth	0.0762																								
Back Depth	0.0254																								
Total Depth	0.127																								
Core Layers	2																								
CoreWeb Fillet Radius		0.005																							
IsoGrid Fillet Radius		0.005																							
Merge Tol	0.025																								
Grid Zoom	0.99																								
Segment Shown	1																								
Srink Factor	0.12																								

Status 21 elems with bad aspect ratios



WHOLE MIRROR OR SEGMENT SUPPORTS



Arnold Lightweight Mirror Modeler (Ver 2.0)

Outer Dia	2
Inner Dia	0.25
Cell Width	0.3
Lip Inner	0.05
Segment Lip	0.05
Mirror Lip	0.1
Num Rings	2
Sgmt Span	1.25
Sgmt Gap	0.11
Merge Tol	0.025
Grid Zoom	0.99
Segment Shown	1
Srink Factor	0.12

Model Statistics	
6830	num Nodes
15751	num Elms
206.4664	Weight (kg)
17.01546	Area (m ²)
12.13405	W/A (kg/m ²)

Supports

☐ Each Segment

☒ Whole Mirror

☒ Show Whole Grid

☐ Show Supports

☐ Show Fillets

DISPLAY GRID

DISPLAY MODEL

WRITE MODEL

SAVE **RESTORE**

MERGE NODES

Modal (PSD)	Boule Mapping
Grid Options	Optical
Reals	Core
Hexapod	Axial
Radial	Inertial Loads

☐ Do Radial Support

Num Points 12

Support Length 0.15 (m)

Spring Rate 2000 (N/m)

Start Angle 0 (deg)

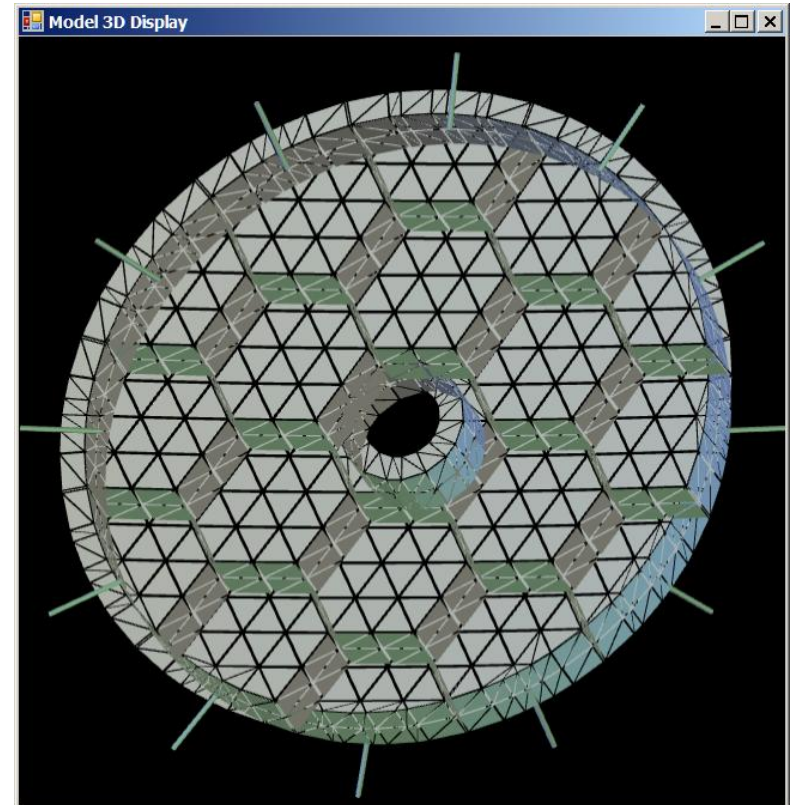
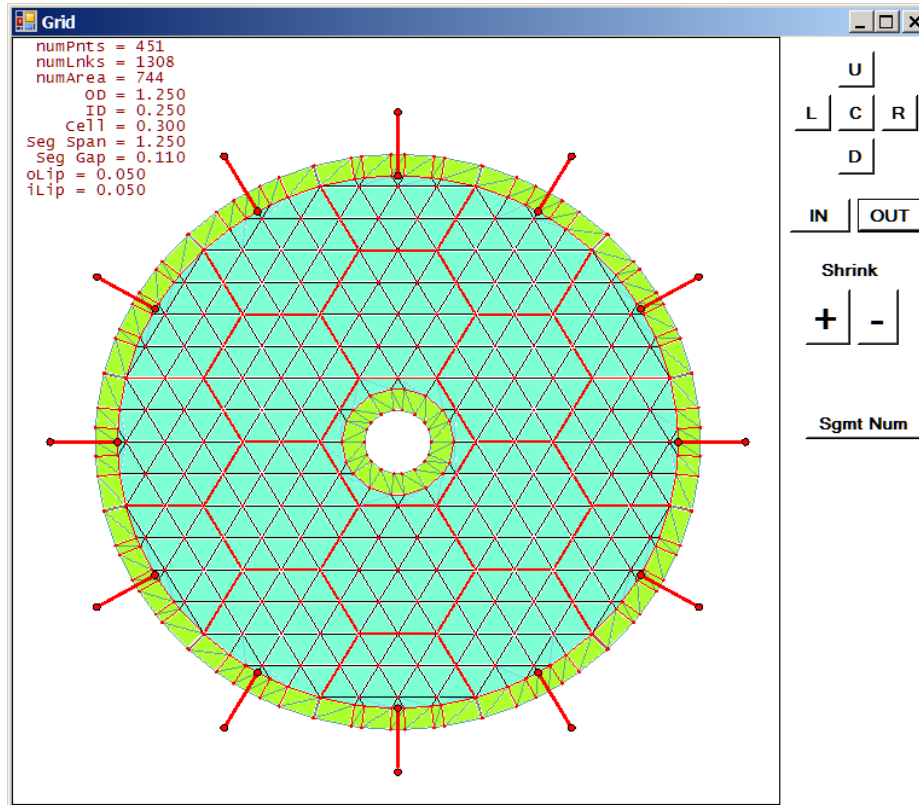
Fitting Mass 1 (kg)

Acceptable Near 1E-05 (m)

Status 21 elms with bad aspect ratios



USER CAN ADJUST AND OPTIMIZE





AXIAL AS WELL AS RADIAL STYLES



Arnold Lightweight Mirror Modeler (Ver 2.0)

Outer Dia
Inner Dia
Cell Width
Lip Inner
Segment Lip
Mirror Lip
Num Rings
Sgmt Span
Sgmt Gap
Merge Tol
Grid Zoom
Segment Shown
Sink Factor

Supports
☐ Each Segment
☒ Whole Mirror

☒ Show Whole Grid
☒ Show Supports
☐ Show Fillets

DISPLAY GRID
DISPLAY MODEL
WRITE MODEL
SAVE RESTORE
MERGE NODES

Modal (PSD) Boule Mapping
Grid Options Optical Reals Core Hexapod Axial Radial Inertial Loads

☒ Do Axial Support

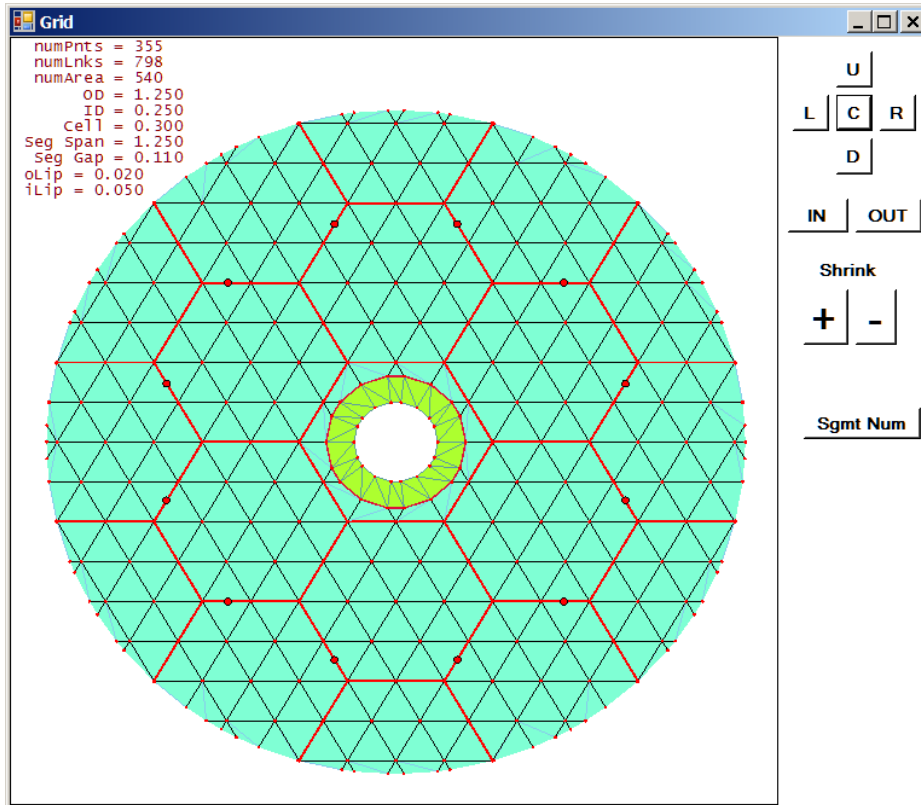
Pnts	Diameter (m)	Start Ang (deg)	Spring Rate (N/m)
12	0.85	15	2000
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0
0	0	0	0

Fitting Mass (kg)
Support Ground (m)
Acceptable Near (m)

Status Finished Building Grid



MODEL TEST MOUNTS, ETC





ANY VARIETY OF HEXAPOD SUPPORT



Arnold Lightweight Mirror Modeler (Ver 2.0)

Outer Dia	2
Inner Dia	0.25
Cell Width	0.3
Lip Inner	0.05
Segment Lip	0.05
Mirror Lip	0.1
Num Rings	2
Sgmt Span	1.25
Sgmt Gap	0.11
Merge Tol	0.025
Grid Zoom	0.99
Segment Shown	1
Sink Factor	0.12

Model Statistics	
6830	num Nodes
15751	num Elms
206.4664	Weight (kg)
17.01546	Area (m ²)
12.13405	W/A (kg/m ²)

Supports

☐ Each Segment

☒ Whole Mirror

☒ Show Whole Grid

☐ Show Supports

☐ Show Fillets

DISPLAY GRID

DISPLAY MODEL

WRITE MODEL

SAVE **RESTORE**

MERGE NODES

Modal (PSD)	Boule Mapping						
Grid Options	Optical	Reals	Core	Hexapod	Axial	Radial	Inertial Loads

☐ Do Hexapod

Upper Diameter 1.2 (m)

Lower Diameter 1.6 (m)

Height (ground) 0.5 (m)

Start Angle 0 (deg)

Upper Spread 30 (deg)

Lower Spread 5 (deg)

Acceptable Near 1E-05 (m)

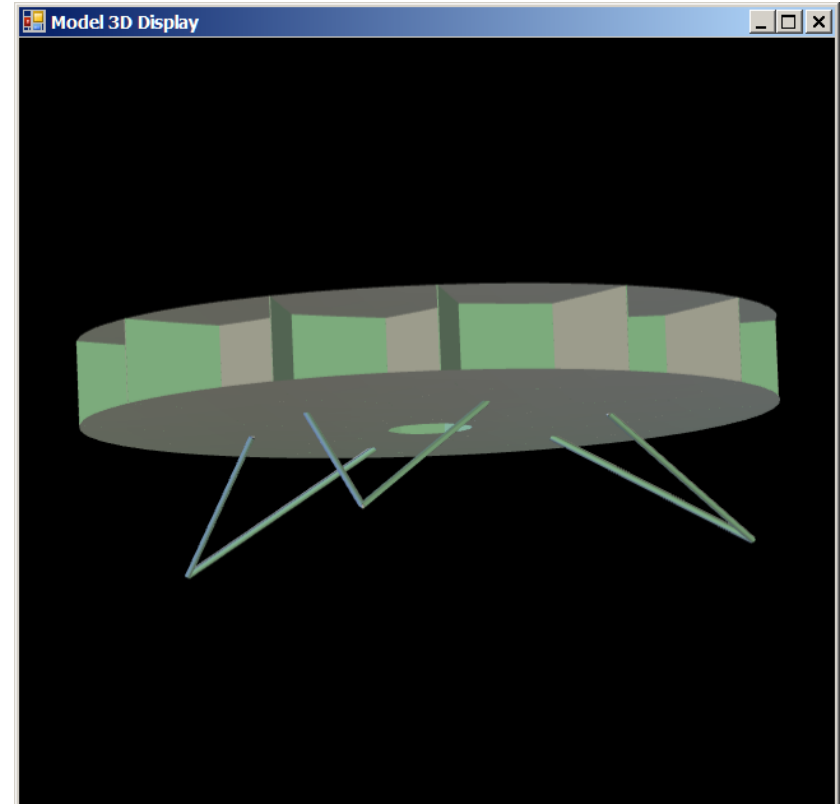
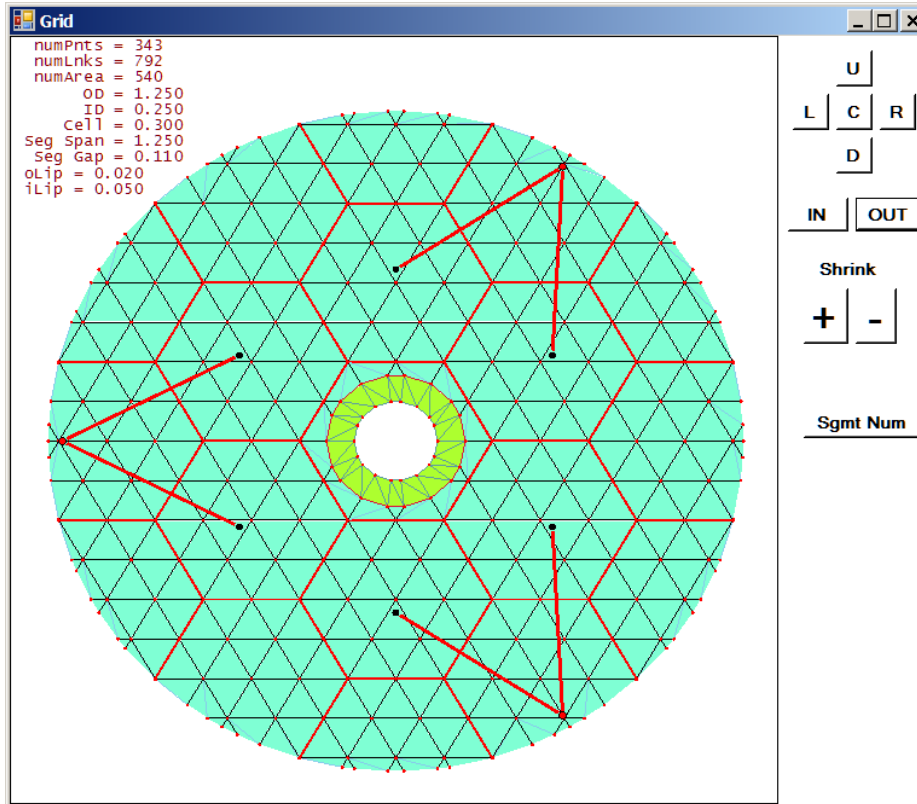
Spring Rate 200000 (N/m)

Fitting Mass 1 (kg)

Status 21 elms with bad aspect ratios



WHOLE MIRROR OR EACH SEGMENT





GENERATE STATIC LOADING CONDITIONS



Arnold Lightweight Mirror Modeler (Ver 2.0)

Outer Dia: 2
Inner Dia: 0.25
Cell Width: 0.3
Lip Inner: 0.05
Segment Lip: 0.05
Mirror Lip: 0.1
Num Rings: 2
Sgmt Span: 1.25
Sgmt Gap: 0.11
Merge Tol: 0.025
Grid Zoom: 0.99
Segment Shown: 1
Sink Factor: 0.12

Model Statistics

6830	num Nodes
15751	num Elms
206.4664	Weight (kg)
17.01546	Area (m ²)
12.13405	W/A (kg/m ²)

Supports

☐ Each Segment
☒ Whole Mirror

☒ Show Whole Grid
☐ Show Supports
☐ Show Fillets

DISPLAY GRID
DISPLAY MODEL
WRITE MODEL
SAVE **RESTORE**
MERGE NODES

Modal (PSD) **Boule Mapping**
Grid Options **Optical** **Reals** **Core** **Hexapod** **Axial** **Radial** **Inertial Loads**

Accel X **Accel Y** **Accel Z**

1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0	0
6	0	0	0
7	0	0	0
8	0	0	0

☐ Calculate Static LCs
num Loadcases: 0

Status 21 elems with bad aspect ratios



GENERATE DYNAMIC LOADING SETS



Arnold Lightweight Mirror Modeler (Ver 2.0)

Outer Dia: 2
Inner Dia: 0.25
Cell Width: 0.3
Lip Inner: 0.05
Segment Lip: 0.05
Mirror Lip: 0.1
Num Rings: 2
Sgmt Span: 1.25
Sgmt Gap: 0.11
Merge Tol: 0.025
Grid Zoom: 0.99
Segment Shown: 1
Sink Factor: 0.12

Model Statistics

6830	num Nodes
15751	num Elms
206.4664	Weight (kg)
17.01546	Area (m ²)
12.13405	W/A (kg/m ²)

Supports

☐ Each Segment
☒ Whole Mirror

☒ Show Whole Grid
☐ Show Supports
☐ Show Fillets

DISPLAY GRID
DISPLAY MODEL
WRITE MODEL
SAVE **RESTORE**
MERGE NODES

Grid Options | **Optical** | **Reals** | **Core** | **Hexapod** | **Axial** | **Radial** | **Inertial Loads**
Modal (PSD) | **Boule Mapping**

☒ Calculate Modes
num Modes: 10

	f1	f2	f3	f4	f5	f6	f7
f	0	0	0	0	0	0	0
g2	0	0	0	0	0	0	0

☐ Calculate X PSD

f	0	0	0	0	0	0	0
g2	0	0	0	0	0	0	0

☐ Calculate Y PSD

f	0	0	0	0	0	0	0
g2	0	0	0	0	0	0	0

☐ Calculate Z PSD

Status: 21 elems with bad aspect ratios



(IN WORK) ULE CTE MAPPING



Arnold Lightweight Mirror Modeler (Ver 2.0)

Outer Dia	2	Model Statistics		Supports		DISPLAY GRID	
Inner Dia	0.25	6830	num Nodes	<input type="radio"/> Each Segment	DISPLAY MODEL		
Cell Width	0.3	15751	num Elems	<input checked="" type="radio"/> Whole Mirror	WRITE MODEL		
Lip Inner	0.05	206.4664	Weight (kg)	<input checked="" type="checkbox"/> Show Whole Grid	SAVE RESTORE		
Segment Lip	0.05	17.01546	Area (m ²)	<input type="checkbox"/> Show Supports	MERGE NODES		
Mirror Lip	0.1	12.13405	W/A (kg/m ²)	<input type="checkbox"/> Show Fillets			

Num Rings: 2
Sgmt Span: 1.25
Sgmt Gap: 0.11
Merge Tol: 0.025
Grid Zoom: 0.99
Segment Shown: 1
Sink Factor: 0.12

Grid Options | **Optical** | **Reals** | **Core** | **Hexapod** | **Axial** | **Radial** | **Inertial Loads**
Modal (PSD) | **Boule Mapping**

Input Boule Data	Input Boule Assign Data
Write Boule Data	Write Boule AssignData
Load Boule Data	Load Boule AssignData
List Boule Data	Map Boules to Model

Status 21 elems with bad aspect ratios



FUTURE ENHANCEMENTS



- **FINISH CTE MAPPING**
- **LOCALIZED MESH REFINEMENT AT ATTACHMENT POINTS**
- **REAL CONSTANT BASED COLOR 3D DISPLAY OF MODEL**
- **AUTOMATIC BAD ASPECT RATIO ELEMENT FLAGGING/PLOTTING**
- **HEXAPOD GEOMETRY OPTIMIZATION**
- **EXPAND ANSYS GENERATED DATA SUMMARIES**
- **ABACUS OUTPUT FORMAT (LOW PRIORITY FOR NOW)**
- **NASTRAN OUTPUT FORMAT (NEEDS SPONSOR)**

- **USER MANUAL**
- **TUTORIAL(S) ON HOW TO USE MODELER**
- **SHORT COURSE IN ADVANCED MIRROR DESIGN METHODS**